衝撃荷重を受ける梁の塑性変形——曲げ，伸び及び剪断の相互干渉について

野 中 泰 二 郎

PLASTIC DEFORMATION OF A BEAM UNDER IMPACT LOADING —— INTERACTION EFFECTS OF BENDING, EXTENSION AND SHEARING

By Taijiro NONAKA

Summary

This is a summary of a work already reported on an interaction problem in the field of plastic beam dynamics*.

Theoretical and experimental studies are made of the permanent deformation of clamped beams with constraints against axial displacements at the ends, with an attached mass at the center, and subjected to large transverse dynamic loading. The combined action of bending moments, axial forces and shearing forces is taken account in the plastic range.

In the first part, the interaction problem is considered for a perfectly plastic material. An analysis is presented to determine the permanent deformation of a rigid-perfectly plastic beam due to impulsive loading applied to the central mass, based on a fixed yield surface or interaction relation. An approximate interaction diagram is adopted. Various patterns of the deformation are found to occur, according to the beam dimensions. Ordinarily shearing and bending deformation predominates at early stages of deformation. When constraints against axial motion are present, axial forces come into effect as the deformation proceeds so that interaction of bending and extension plays an important role. When the beam acquires a deflection of the order of the beam depth or greater, the deformation is primarily governed by the axial force, and the axial constraints reduce the deflection by a considerable amount ; whereas the shear effect is found to be small for ordinary beam span-depth ratios with compact cross-section unless the attached mass is small compared to the beam mass. The shear effect becomes larger for short beams and non-compact sections subjected to impulsive loading. Unless the mass ratio is small, the major portion of the deformation occurs under a one degree of freedom mode, the two halves of the beam rotating about the supports.

In the second part of the theoretical approach, effects of strain-rate sensitivity, elasticity, and duration of load pulse are also taken into account in an approximate manner based on this deformation pattern ; the one degree of freedom mode assumption facilitates the inclusion of these effects in the

* T. Nonaka, Report of Engineering Division, Brown University, NSF-GP 1115/18, December, 1964

analysis. For the same total impulse, a load with a flatter load-time relation produces a smaller deformation and impulsive loading (duration time approaching zero) gives the largest deformation. The asymptotic approach to the limiting deformation of impulsive loading is faster when the elastic effect is included and also speeded by axial constraints. A rigid-plastic beam undergoes a smaller permanent deformation than an elastic-plastic beam for a flat load pulse but the opposite is true for a load close to impulsive loading with the same total impulse. Plastic strains are assumed to be concentrated in small regions at plastic hinges for the evaluation of the strain-rate, until the transition to the string stage occurs.

Experiments were performed using aluminum alloy 6061-T6 and mild steel specimens, and showed a general agreement with the theoretical predictions from the latter approach. The rigid-perfectly plastic analysis overestimated the deformation but served as a first approximation. A substantial reduction in the permanent deformation due to the axial constraints was confirmed. The localized plastic deformation was observed clearly in the 6061-T6 aluminum alloy specimens, and is displayed in pictures of the deformed specimens.